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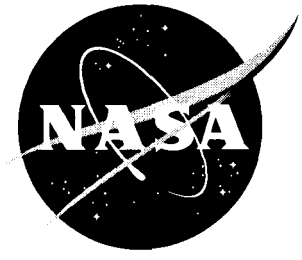

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October 2003

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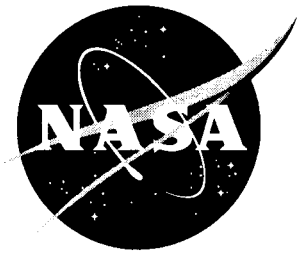

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Summary

Low-boom design studies of High Speed Civil Transport (HSCT) concepts were based on the expectation that a beginning-cruise overpressure of about 1.0 psf might be achieved if the configuration's geometry was low-boom tailored during its design. However, ongoing environmental and human-response studies of sonic-boom noise indicated that 1.0 psf ground overpressures might still be too annoying. This noise dilemma led to studies of a smaller lighter vehicle, a Supersonic Business Jet (SBJ), which would generate lower, more tolerable and/or acceptable ground overpressures. To determine whether the design methods and the methodology for designing the HSCT could be successfully applied to the SBJ, and how much overpressure reduction might be achieved, an SBJ concept was designed at the Langley Research Center. The concept would cruise at Mach 2, have a range of 4000 nautical miles, carry 10 passengers with baggage, and generate a 0.50 psf or less ground overpressure under the flight path at start of cruise. Results of this effort indicated that designing a 10-passenger, low-boom SBJ for a ground overpressure of 0.5 psf was just as technically demanding as designing a 300-passenger, low-boom HSCT for a ground overpressure of 1.0 psf. In this report, the sources of these design problems are identified, and ideas for addressing them are discussed.

Introduction

In the early 1960's, and continuing through to the 1990's, the technologies and methodologies associated with the design of supersonic-cruise vehicles were studied by a variety of research institutions. The initial focus of these studies was the determination of the basic aerodynamic, structural, and propulsion technologies that could lead to a technologically sound, commercially viable, and environmentally acceptable aircraft. Methods that could be the basis of these technologies were applied to the preliminary designs of the Supersonic Transport (SST), and later to the Supersonic Business Jet (SBJ).

The sonic-boom characteristics of these concepts were calculated with the latest far-field theories developed by Whitham, reference 1, and Walkden, reference 2. In 1965, however, a NASA paper by McLean, reference 3, showed that sonic-boom pressure signatures from a boom-constrained aircraft flying at low-supersonic speeds during the climb-acceleration phase of the mission flight could retain desirable (non-N-wave) near-field overpressure characteristics. This discovery led to the expectation that practical possibilities existed for reducing sonic-boom noise; possibilities realized by shaping the pressure signature through complete configuration geometry tailoring to control the location and rate of growth of the aircraft's volume and lift.

With the introduction of sonic boom minimization theory, references 4 and 5, sonic boom minimization methodology could now be part of the preliminary design process, as demonstrated in reference 6. By modifying these sonic-boom minimization ideas, reference 7, trade-offs between wave-drag and sonic-boom could be made by enhancing the flexibility of the minimization methods. At the same time, the initial codes for predicting sonic-boom propagation in a constant-pressure atmosphere, reference 8, were generalized in references 9 to 12, so that stratified-atmosphere propagation effects could be included. It now became possible to combine low-boom design and analysis methods with high-aerodynamic-efficiency design and analysis tools to provide a practical and useful methodology for the preliminary design of low-boom, commercially-viable, supersonic-cruise aircraft. Most of these design tools and their updated versions are described in references 13 through 23.

Concepts designed with these design and analysis tools demonstrated that an SST, with its geometry tailored for low-sonic-boom, would incur sizeable weight and/or range penalties compared with the weight and range of a concept whose design was constrained only by aerodynamic efficiency. Moreover, the high beginning-cruise weights on SST concepts resulted in lift equivalent areas that often exceeded equivalent areas from the aircraft's volume by a factor of from three to four. Thus, aircraft lift was seen to be the dominant factor in generating sonic-boom disturbances on the ground. So, it became imperative that the longitudinal and lateral gradients of lift had to be carefully tailored for both low-boom and aerodynamic efficiency.

During the High Speed Civil Transport (HSCT) studies, which followed the earlier SST and High Speed Research (HSR) Programs, it was extremely difficult to achieve a theoretical ground overpressure of 1.0 psf or less with concepts that had engine nacelles conventionally located under the trailing edge of the wing. However, there were results that indicated a goal of 1.0 psf overpressure might be achieved with low-boom tailoring if the engine nacelles could be positioned toward the aft end of the vehicle. Possible nacelle locations were behind the wing trailing edge on the aft fuselage, or under/over the trailing edge of an aftward extended inboard panel of the wing. As these encouraging possibilities were being found and studied, there were new psychoacoustic studies being published that suggested ground overpressures of about 1.0 psf were still overly annoying to a significant number of people.

Since there were unresolved noise and technical difficulties with HSCT-sized aircraft, a smaller aircraft was considered as a better candidate for a low-boom concept. This smaller vehicle, such as a SBJ, would carry 8 to 10 passengers instead of the 250 to 300 passengers in an HSCT. It would have a cruise Mach number between 1.6 and 2.0 instead of between 2.0 and 2.4, and a mission range of between 3500 to 4500 instead of between 5000 and 6500 nautical miles. Due to the reduced weight and size of the SBJ, it was hypothesized that an overpressure of 0.5 psf on the ground at start of cruise under the flight path could be achieved. If such boom levels were possible for a SBJ with that mission, and if a limited number of overland flights each day would be considered tolerable, then a low-boom SBJ might be technologically possible, economically viable, and environmentally acceptable.

In this paper, the preliminary design of a low-boom SBJ concept is described and discussed to demonstrate the capability of the sonic-boom analysis methods, and the applicability of the low / reduced-boom design methodology. Difficulties and problems inherent in the design of this size vehicle will be highlighted and addressed in the light of generalized low/reduced-boom design. General suggestions for solutions of technical problems will be mentioned, and where possible, demonstrated by incorporating them into the concept's geometry.

Nomenclature

A_E	equivalent area, ft^2
ΔA_E	increment in equivalent area, ft^2
b	wing span, feet
$\bar{c}$	mean aerodynamic chord, ft
C_L	cruise or takeoff lift coefficient
F(y)	Whitham F-function of parameter y, $ft^{1/2}$
h	cruise altitude, ft
l_e	effective length of the aircraft, ft
$l_{e,f}$	effective length to maximum of curve A in figure 5, ft
$l_{e,p}$	effective length to peak of curve B in figure 5, ft
L/D	lift to drag ratio
M	cruise Mach number
p	ambient pressure, psf
Δp	overpressure in the aircraft's flow field, psf
q	dynamic pressure, psf
S	wing reference area, ft^2
W_c	aircraft weight at start of cruise, lb
W_{eff}	aircraft weight used to calculate a low-boom F-function and equivalent areas, lb
ΔW_c	increment in effective beginning-cruise weight, W_{eff} - W_c, lb
x	distance along the longitudinal direction, ft
x_e	effective distance along the longitudinal direction, ft
y	spanwise direction or Whitham F-function effective length parameter, ft
y_f	length of nose bluntness "spike" on Whitham F-function, ft
β	Mach number parameter defined by $(M^2 - 1.0)^{1/2}$

ξ distance to end of constant F(y) section on a "hybrid" Whitham F-function, ft

η ratio of F-function "ramp" slope to the acoustic signal slope on F(y) vs. y plot

λ length of the positive section of the low-boom F-function, ft

Mission Requirements

Low-boom characteristics of an HSCT or SBJ concept can be calculated with as few as four parameters: (1) cruise Mach number; (2) beginning cruise weight; (3) beginning cruise altitude; and (4) ground overpressure signature shape. There will also be gross takeoff weight limits, takeoff and landing requirements, airport and community noise constraints, customer comfort, purchase price, as well as other design constraints that must be met so the concept would be technically, environmentally, and economically viable. However, the four parameters previously mentioned, along with (5) range, and (6) number of engines, will determine, to a large extent, the engine size, beginning-cruise weight, wing planform shape and area, fuselage length, and configuration layout in the preliminary design. In this paper, the preliminary design of a low-boom SBJ concept will need to satisfy the following requirements:

Range	=	4000 nmi
Cruise Mach Number	=	2.0
Number of Passengers	=	10
Number of Crew	=	2
Maximum Nose/Tail Shock Overpressure	=	0.5 psf or less
Number of Engines	=	2

Design of the Low-Boom Business Jet Concept

Three important lessons were learned during the previous cycles of low-boom concept design, wind-tunnel model testing. The first was that wing lift effects (lifting length, center-of-lift location, lift gradients) had to be carefully tailored, the second was that engine nacelle geometry, location, and interference lift had to be carefully integrated into the wing-fuselage-fin configuration, and the third was that beginning-cruise altitude and weight strongly affected aerodynamic, low-boom, and engine performance. This third design consideration mandated a low equivalent area for a given beginning-cruise weight and cruise altitude so that ground overpressures were within specifications, a maximum-possible lift/drag ratio was achieved, and deleterious effects on the atmospheric ozone layers were kept to a minimum. There were, of course, other lessons learned during the low-boom design and the "boom-softening" activities. However, the three lessons listed - lift tailoring, nacelle integration, beginning-cruise altitude selection - had the highest impact on the design and geometric tailoring of the total configuration which would meet all the mission requirements, especially those for low sonic boom.

Much of the discussion about the SBJ concept's design features is focused on the wing planform since lift is usually a major source of sonic-boom disturbance. Lengthening the wing allowed the lift to develop gradually, and improved the potential for reduced sonic boom. For a fixed span, the extra wing area decreased the wing aspect ratio and lead to drag penalties from both an increased skin-friction, and a higher drag-due-to-lift factor. So, as a goal, an aspect ratio of about 2.0 was considered a desirable design goal.

The concept in this report was given a canard to provide control during takeoff, landing, and low-speed operations. A canard needed special consideration because its location affected the placement of the crew's cabin and access to the passenger compartment. At the same time, its area and distance from the wing's aerodynamic center and potential center of gravity affected its control effectiveness. Also important was nacelle-wing integration because the nacelle inlet-lip location and nacelle-wing interference lift were potentially strong sources of flow-field disturbances. Both of these design considerations are discussed in the following sections.

The preliminary design of the low-boom business jet concept employed most of the same methods and procedures employed in the designs of low-sonic-boom HSCT concepts; methods that were presented and discussed in reference 6. Subsequent modifications and updates were reported in references 8 to 24.

Preliminary SBJ concept design tasks were presented and discussed in the following order:

- Initial concept layout, and cruise performance estimation;
- Weight constraints imposed by low-boom constraints;
- Weights, engine selection, and takeoff calculation;
- Fuel tank volume sizing and placement;
- Center of gravity calculation;
- Equivalent areas (smooth and continuous) to meet nose-shock constraints;
- F-functions (from smooth and continuous equivalent areas);
- F-functions (from non-smooth equivalent areas, e.g. engine nacelles); and
- Ground-level pressure signature predictions from the summation of F-functions,
- Check of canard rotation capabilities and rudder effectiveness.

Most of these tasks were concerned with the aerodynamic design and analysis of the configuration and were required for both mission-performance and sonic-boom determinations. They were carried out concurrently with the design of the wing-fuselage structure, integration of the nacelles, the fin, and the canard, and the accommodation of passenger comfort. Their sequencing was not emphasized in this paper so as to focus on sonic-boom constraints and their impact on preliminary design geometry. If sonic-boom overpressures or mission performance specifications were not met as these tasks were performed, the concept's design was modified to correct either the sonic-boom and/or mission-performance deficiencies.

Concept Layout

The initial shape of the concept was obtained from tailoring applied to the fuselage length, fuselage volume, and the wing planform. Then, the canard and fin were approximately sized and positioned. Finally, the engine nacelle location was selected. These selection and sizing processes are discussed in the following sections.

Wing and Fuselage

Low sonic boom constraints and high-supersonic cruise efficiency required a wing with a long planform length, a low aspect ratio, and a wing thickness in the 2.5 to 3.0 percent range for low wave drag. Although not essential for lateral stability, some dihedral was used to aid take-off ground clearance, and to assist in achieving low-boom tailoring. At this stage of the design effort, there was only a vague idea of what the gross takeoff and beginning cruise weights might be. Since there was little background information available on low-boom SBJ's, an estimate of these weights was made using conventional SBJ

and HSCT data. The initial effort to have a viable low-boom, high aerodynamic efficiency wing resulted in the wing planform shown in figure 1.

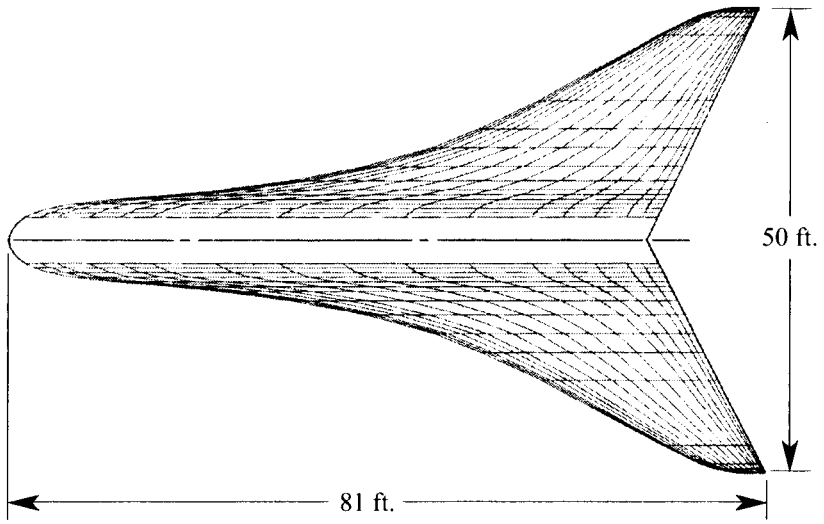
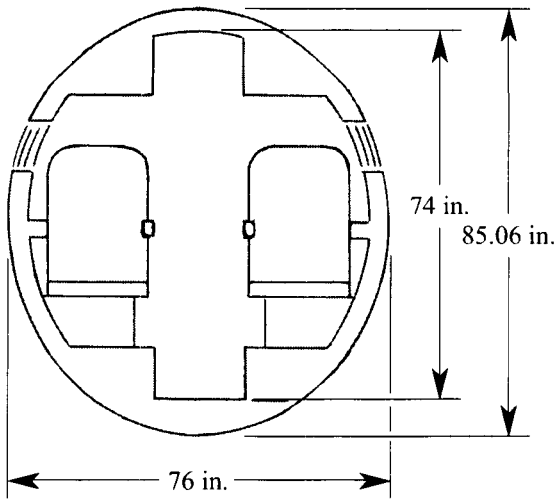


Figure 1. Initial wing planform of a low-boom SBJ concept.

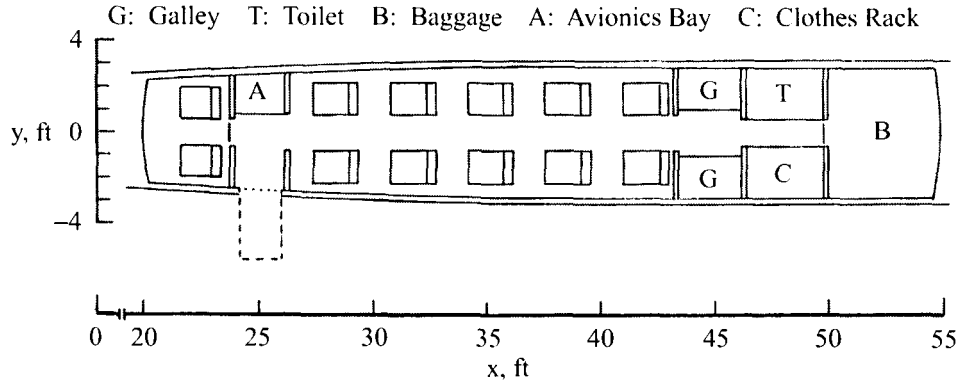
The length and width of a fuselage were sized for: 10 passengers and their baggage; 2 crew members and a crew's cabin; nose and main landing gear stowage; avionics equipment; and most of the mission fuel. Fuselage fuel tanks were permitted in the SBJ, but not in the HSCT concepts (except for aft-fuselage fuel tanks to aid in center of gravity trim).

All fuselage sections were represented as circles in the three-view schematics. A circular fuselage would be the best pressure vessel, but the maximum cabin height would have been only about 69 inches which was not acceptable. So, the passenger cabin cross-sections were changed from circular to elliptical for more cabin height, as shown in figure 2.



(a) Concept cabin cross section at x = 55 feet.

Figure 2. Sketches of passenger cabin with two-abreast seating.



(b) Longitudinal section along crew and passenger cabin.

Figure 2. Concluded.

With a seat width of 20 inches, an aisle width of 20 inches, and a cabin height of 74 inches, these initial passenger accommodations could be considered "Spartan". With improved acoustic and thermal insulation as well as advanced structural materials and construction techniques, the wall thickness might be reduced from 4.0 to 2.5 inches. Then, the crew-passenger cabin could be more circular and lighter, making it a more structurally efficient pressure vessel.

The wing from figure 1 was joined with a fuselage, whose typical cabin section was shown in figure 2, to form the initial wing-fuselage layout of the configuration shown in figure 3.

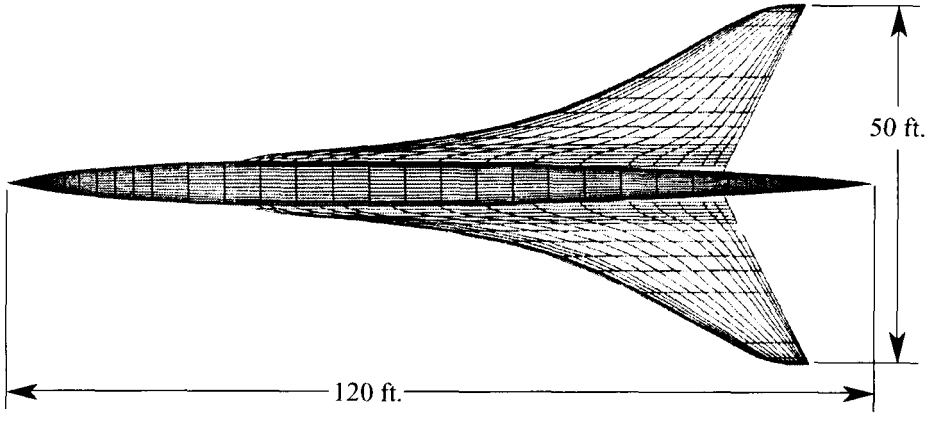


Figure 3. Initial fuselage and wing planform for a low-boom SBJ concept.

The fuselage fineness ratio on this 10-passenger SBJ was smaller than on a 300-passenger HSCT configuration (The number of passengers was less, but the size of the passenger wasn't.). A small wave-drag penalty accompanied this decrease in the fuselage fineness ratio, and was the first of several to be incurred during the design of this concept.

The wing's curved leading edge started with a strake at the wing-fuselage junction; the kind of strake used successfully on the HSCT-10B concept and wind-tunnel model, references 20 and 21. This strake initiated the upwash field and the low-boom-tailored wing lift so that both could be smoothly spread over the longest practical distance. The low-boom tailored growth of wing volume and lift limited the growth of forward fuselage cross-sectional area. Although helpful for sonic boom, the severity of the strake's

leading edge sweep also had a detrimental effect on the aerodynamic drag-due-to-lift. Along with leading edge sweep limitations, care had to be exercised to make fuselage contours transition smoothly from nose section to passenger compartment to aft body section so as to minimize wave drag penalties. Moreover, the combined equivalent areas from the fuselage volume, the wing volume, and the wing lift had to match those prescribed for low-boom characteristics while simultaneously providing safety and some measure of comfort in the passenger compartment.

Aerodynamic efficiency and low-boom characteristics were also enhanced by sweeping the wing trailing edge - "notching". The "notching" was limited to avoid severe structural weight penalties arising from the increase in structural aspect ratio. Wing camber and twist was kept modest to reduce structural complexity and fuselage-wing integration problems. A shallow wing dihedral angle was used to extend the lifting length for low-boom. Since the wing-tip panels were too small for control surfaces, their dihedral angle was increased to further extend the wing's effective lift length.

The fuselage camber line at the nose was aligned with the cruise freestream velocity vector, and reflexed upward along the aft-fuselage to permit 8 to 10 degrees of rotation at takeoff. Along the passenger compartment, the fuselage center line slope was equal to the slope of the wing root chord center section. This compromised the aerodynamic efficiency (another small drag increment) somewhat, but it simplified the wing structure, and facilitated wing-fuselage integration.

Canard

The canard was to be used only for rotation during takeoff, and for control during landing and low-speed maneuvering. Initially sized from canards found on previous SBJ concepts, its position along the nose of the concept provided a long moment arm for control while removing a minimum of volume from the low-boom area distribution of the nose. *During the cruise segment of the mission, it would be set at zero-lift.* At this setting, it would contribute only volume effects to the concept's flow-field disturbances, would not generate lift-induced downwash to impair the wing's lifting efficiency, and would not change the concept's low-boom lift distribution.

Fin

A single fin with an all-moving rudder was selected, and positioned at the aft end of the fuselage. Its initial area was sized by proportioning the fins on HSCT concepts and on previously-designed SBJs. Takeoff control effectiveness of the rudder would be calculated later, after the weights, engine size, and center of mass of the concept had been calculated.

Engine Nacelle Location

Four options were considered for engine nacelle positions: (1) on the aft fuselage behind the wing trailing edge; (2) under the trailing edge of an extended wing center-section; (3) above the trailing edge of the extended center-section used in option (2); and (4) under the wing trailing edge just outside the landing gear.

With option (1), there would be no nacelle-wing interference lift at cruise. Thus, the sonic-boom flow-field disturbances generated by the nacelles would be from volume effects only. If option (2) were employed, nacelle-wing interference lift would be generated and the drag-due to-lift increment from the wing would be reduced. However, there would be additional flow-field disturbances from the reflected inlet-lip shocks, and the interference-lift pressures generated by the nacelles. A tandem-wheel landing

gear arrangement might be needed to keep the main wheels and struts from passing in front of the engine inlets during takeoff and landing. However, if the main gear retracted into the engine nacelles, the wheel struts would not momentarily block the inlets. There would, however, be a drag and weight penalty from the increased nacelle size.

Negative nacelle-wing interference lift would be encountered with option (3). Addition wing lift would be needed to compensate for this decrement with an attendant penalty in drag-due-to-lift. However, the wing would shield the flow field under the concept during cruise from some of the nacelle's volume and lift contributions, and conventional landing gear would be used, as with option (1), permitting aircraft rotation to meet balanced field length requirements.

With option (4), the engine nacelles would be mounted under the wing trailing edge just outside the landing gear. However, past experience has shown that in this location, the inlet-lip shock quickly merges with the reflected inlet lip shock in the near field. This enhanced shock system eventually coalesces with the nose shock in the mid-field and destroys most chances of having a low-boom shaped pressure signature on the ground.

The simplest low sonic boom solution was option (1), so this nacelle-mounting option was used in the design of the Langley SBJ concept. An engine nacelle from a previous similar-sized SBJ concept was used to obtain the initial three-view schematic.

Initial Three View of Concept

All of the configuration components that have been described in the previous sections are seen in the initial three view of the supersonic-cruise business jet concept, figure 4.

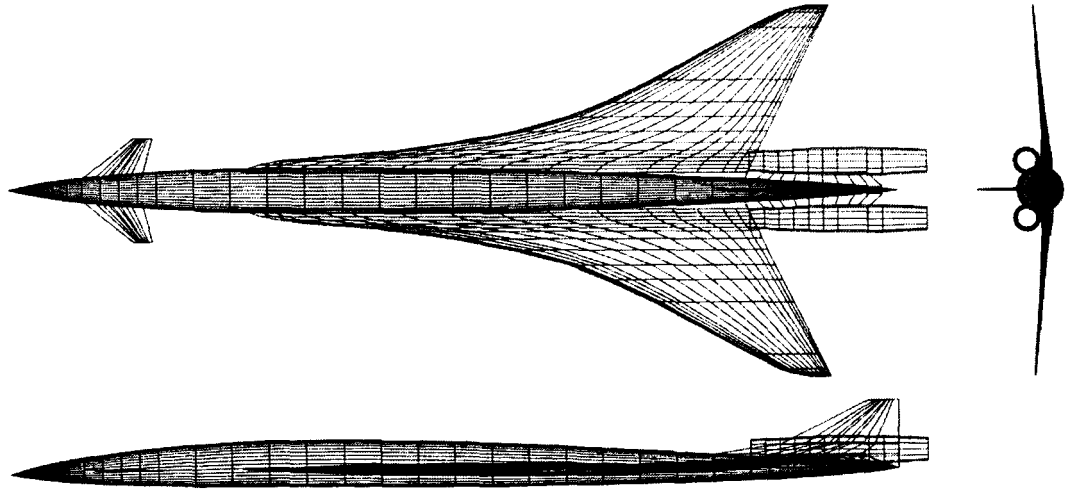


Figure 4. Initial wing-fuselage-nacelle-canard-fin three view of a low-boom SBJ concept.

Low-Sonic-Boom Weights

At this stage in the preliminary design, the beginning-cruise weight of the low-boom concept was an unknown. Weights and planform areas from previous SBJ and low-boom HSCT concepts were sources of data, but were, of course, no more than guidelines because previous HSCT and SBJ missions and configurations were similar, but not identical. The feature common to both types of concepts was that

low-boom HSCT had, and this low-boom SBJ would have, tailored equivalent areas to achieve the desired low-boom overpressure. Plots of these total equivalent areas usually look like those in figure 5.

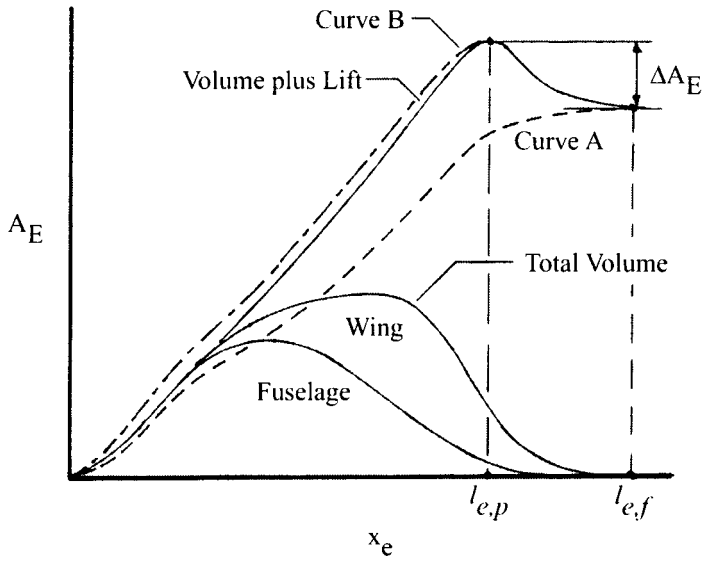


Figure 5. Typical equivalent areas of a low-boom concept without engine nacelles.

Two possible options were possible with these two equivalent-area curves. The first option was to use a low-boom curve for aircraft equivalent areas that peak and level off as seen in curve A. The second option was to use the low-boom curve for equivalent areas that peak then decline to a level determined by the total lift, curve B.

A low-boom equivalent area curve that peaks at the lift level, curve A, often results in significant volume being removed from the wing and/or fuselage to make the low-boom and the vehicle equivalent area curves coincident. This often proves to be a physically unacceptable.

With the second option, a weight increment corresponding to the difference in equivalent area levels, ΔA_E, is calculated from

$$\Delta W_c = \frac{2q\Delta A_e}{\beta}$$

and is added to the beginning-cruise weight to determine the corresponding low-boom equivalent area curve. The beginning-cruise weight would be W_c, and the low-boom beginning-cruise lift which satisfied the second-option, low-boom constraint curve would be the sum of $W_c + \Delta W_c$. This situation could make it difficult, if not impossible, to meet low-boom requirements. Should wing area and/or weight restrictions make it impossible to extend the lifting length to reduce area ΔA_E to zero, then the second option, curve B, would have to be used.

The two types of equivalent area curves in figure 5 indicated the difficulties in trying to achieve a viable conceptual design with low-boom characteristics. Features that promote aerodynamic efficiency often increased tendencies toward higher sonic boom. Plots of relevant parameters that linked a concept's mission performance and its sonic boom characteristics would be useful. Two such parametric plots were used to guide low boom SBJ design decisions.

The first parametric plot was obtained by varying the beginning-cruise weight and altitude for constant overpressures. The low-boom prediction codes of either reference 23 or 24 could be used, but the method of reference 24 was used because it started the fuselage with a conical, rather than a cusped, nose. The conical nose is more volume-length efficient than the cusp-shaped nose, and was an easier shape to put on a full-scale concept as well as a wind-tunnel model.

Three parametric curves of weight versus altitude for varying are presented in figure 6.

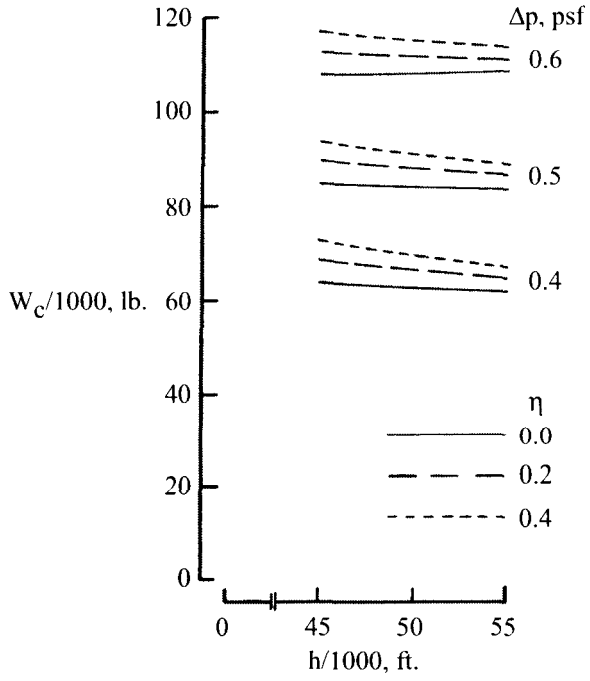


Figure 6. Curves of beginning-cruise weight versus altitude for various ground overpressures at M = 2.

The low-sonic-boom parameters used to calculate the curves in figure 6 were as follows:

M = 2.0; y_f = 8.0 ft.; x = 18.0 ft.; y_f = 8.0 ft.; l_e = 110 ft.
Δp (nose shock) / Δp (tail shock) = 1.0
η = 0.00 ("flattop" signature), 0.20, and 0.40
Δp = 0.4, 0.5, and 0.6 psf

The trends in all but one of the curves indicated that the beginning-cruise weight, for a constant value of the ground overpressure, decreased as beginning-cruise altitude increased. While the "flat-top" pressure signature had desirable low-boom features, it required a lower beginning-cruise weight than a "ramp" signature for a given length and overpressure.

These curves would change somewhat as their input parameters varied during the design process. However, the overall trends would not change, and the magnitude of the weights would not vary markedly from the relative differences in the individual input parameters. Thus, a 110 ft. long configuration that met the requirement for a Δp = 0.4 psf would have to be less than 75,000 lb. at start of cruise, while one that met the requirement for a Δp = 0.5 psf would have to be less than 100,000 lb. For the specifications listed in MISSION REQUIREMENTS, a concept that weighed 75,000 lb. or less at start of cruise would be almost impossible to achieve with present-day composite material technology. Even

using advanced composites on the concept, metal structural components would probably still be a significant part of the empty weight. So, a 85,000 to 95,000 lb beginning-cruise weight was the likely range.

Once the beginning-cruise weight of the SBJ concept had been estimated, a second set of parametric curves - cruise C_L and L/D versus cruise altitude - was calculated and presented in figure 7.

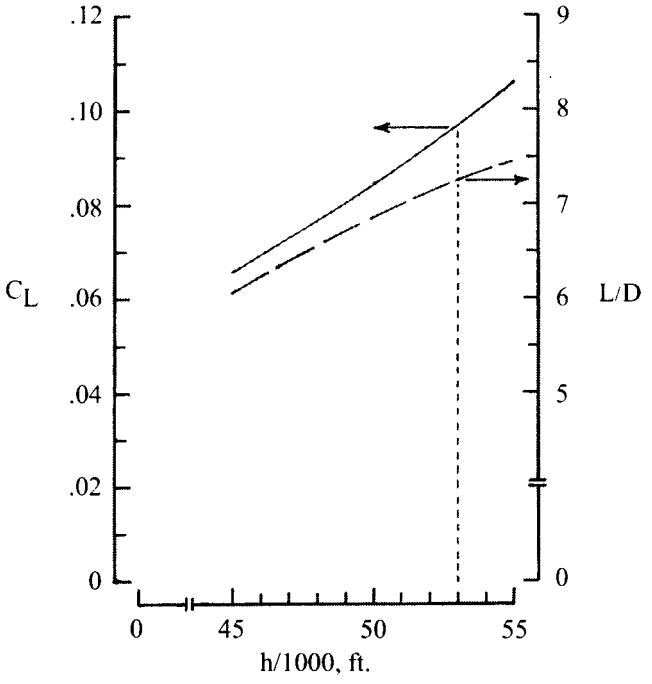


Figure 7. Cruise C_L and L/D versus Cruise Altitude for a constant beginning-cruise weight.

These curves were obtained from performance calculations on a configuration that had evolved over several design iterations; beginning as a design point on a Δp versus W_c and h curve in figure 6.

For the cruise L/D to average 7.0, the beginning-cruise value would have to be somewhat higher since it would decrease during a constant C_L cruise. The curves in figure 7 indicate that for a beginning-cruise altitude of 53,000 feet and a beginning-cruise weight of 88,497 lb, the cruise C_L would be about 0.096. A corresponding start-of-cruise L/D ratio would be about 7.2 and adequate for the mission. If the wing were given a more-optimum camber and twist, the L/D ratio would be increased and an additional margin of mission performance would be obtained.

Charts, such as figures 6 and 7, helped to estimate how the configuration geometry, beginning-cruise weight, and beginning-cruise altitude put constraints on design options through their affect on cruise C_L, L/D ratio, and ground overpressure. When the inevitable component design compromises needed to be made, these charts would be of value in providing a quick estimate of the resultant changes in mission performance and sonic-boom characteristics.

Engine Selection and Takeoff Calculation

In the previous section, the beginning-cruise weight of the low-boom SBJ concept was calculated as 88,497 lb. Based on previous conceptual SBJs whose wings had similar aspect ratios and low-speed

aerodynamic characteristics, it was assumed that the Beginning-Cruise Weight to Gross Takeoff Weight ratio would be about 0.89. From this Beginning-Cruise Weight and weight ratio, the Gross Takeoff Weight was calculated as 99,435 lb. Assuming a Thrust/Weight ratio of about 0.40, two engines of at least 20,000 lb of static thrust each would be required. If the concept's two engines had an optimistic cruise-average SFC = 1.20 lb/lb/hr, and a cruise-average L/D ratio of 7.0, calculations showed that the mission could be performed with 20,300 lb.th. engines. This engine size was accepted and used to calculate takeoff performance.

Takeoff distance was calculated with two 20,300 lb thrust engines and a weight of 99,435 lb at the start of roll. It was assumed that the initial canard could rotate the concept to takeoff attitude at a rate of 2.0 degrees per second. This assumption would be checked later once a center of gravity and a longitudinal moment of inertia had been estimated.

Takeoff calculation results showed that, without flaps, the concept would need almost 7000 feet to lift off and clear a 35-foot obstacle with a maximum $C_L = 0.50$. This takeoff length was considered too long. However, with plain flaps and a maximum $C_L = 0.55$, calculation results showed that takeoff could be achieved in 6000 feet; a length deemed acceptable. So, the design was continued with the assumption that flaps could be incorporated into the wing design. A balanced field length calculation was not done at this preliminary stage of design, but it would be necessary if the concept were considered a serious candidate for further study. APPENDIX A lists the data derived thus far.

Mission Fuel Weight and Fuel-Tank Volume

Along with the calculation of the empty, beginning-cruise, and gross takeoff weights, the weight-estimation method of reference 25 predicted that 49,336 lb of fuel would be required for the mission, and 5,966 lb of the mission fuel would be needed for reserves. The minimum required fuel-tank volume was about 1,143 ft^3, but extra volume for fuel transfer and unusable fuel would also be necessary. Although the wing planform had been shaped for low sonic boom and sized for low drag, there was still room for several fuel tanks and the main landing gear struts. After fuselage volume had been allotted for a crew of two, for ten passengers, and for passenger baggage, there was volume for fuel and the main landing gear wheels. Using most of available volume in the wing and the fuselage for fuel tanks, it was found that over 63,000 lb of fuel could be carried. Thus, it seemed there was sufficient extra tank volume for transfer and storage so the concept might be trimmed by fuel transfer during the mission.

Center of Gravity Calculation

After the preliminary weights were calculated, the empty-weight and zero-fuel-weight components and their respective centers of gravity were estimated (APPENDIX B). Then, the center-of-mass of the fuel in each tank in the fuselage and wing was estimated (APPENDIX C). Finally, the forward and aft center of gravity boundaries were calculated (APPENDIX D).

During the mission, fuel was to be transferred to keep the aircraft balanced. However, it was found that this plan could not be realized during all subsonic and supersonic segments of the mission. Full aft-fuselage fuel tanks and a large shift in center of lift as the concept moved through the speed ranges (APPENDIX E), made self-trimming difficult although most of the supersonic cruise segment could be flown in a self-trimmed condition.

The drag penalty suffered by requiring the use of canard and/or wing control surfaces for trim would mean the consumption of extra fuel. So, while a drag penalty would be expected from the tailoring applied to achieve low-sonic-boom benefits during cruise, an additional drag penalty would come from

the trim drag that occurred during other segments of the mission. The extra fuel needed by these drag penalties would have to be part of the overall fuel budget.

Equivalent Areas and F-functions (Without Nacelles)

The sonic-boom evaluation was started by calculating the equivalent areas contributed by the fuselage, wing, canard, and fin volumes with the methods described and discussed in references 6 and 13. Wing lift equivalent areas were calculated with the method described in reference 6 and updated in reference 14. All of these equivalent area distributions could be directly summed because all of these distributions were smooth and continuous. The fuselage equivalent areas were then low-boom tailored until the summed aircraft equivalent areas closely met the theoretically ideal equivalent area distribution up to the station where the F-function expansion began. The lower fineness ratio of the fuselage on the SBJ spread fuselage area contributions to each longitudinal station over lengths with appreciable area gradients. This made it more difficult, though not impossible, to low-boom tailor the fuselage normal areas quickly and satisfactorily. Equivalent areas from the engine nacelles were not added to the wing, fuselage, lift, and fin equivalent area sum for reasons explained in the *Nacelle F-function* and *Combined F-Functions And Pressure Signatures* sections which follow.

As previously mentioned, the canard would be used only for takeoff, landing, and low-speed control, *and would be set at zero-lift* during cruise. In this mode, the canard contributed volume equivalent areas, but not lift and interference-lift equivalent areas to the total equivalent areas for achieving the desired ground overpressure constraint under the flight path at the start of cruise.

Iterating the design of the concept to meet mission constraints resulted in the conceptual SBJ shown below in figure 8.

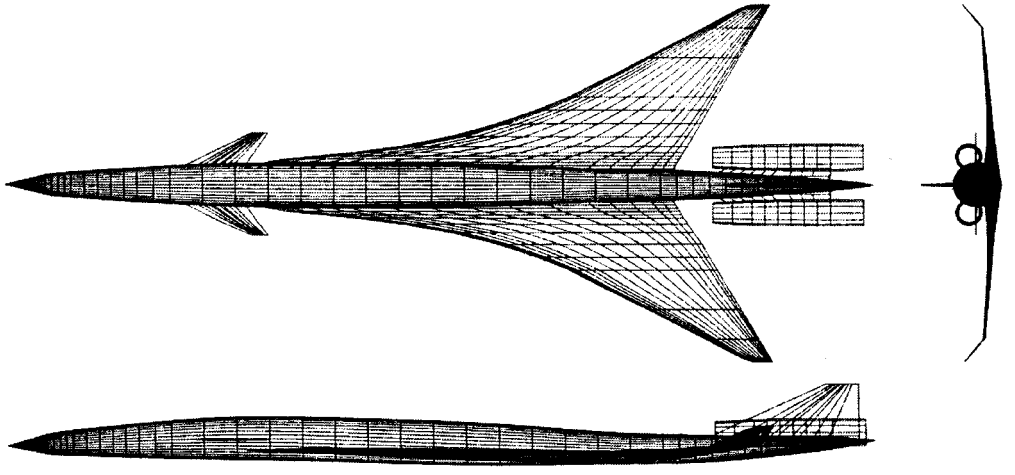


Figure 8. Three view of a low-boom SBJ concept.

At each step in the iteration, an ideal low-boom equivalent area curve, calculated at the design cruise Mach number, beginning-cruise altitude, weight, and would be compared with a longitudinal distribution of the volume (excluding nacelle volume) and lift equivalent areas of the supersonic-cruise business jet concept. One such set of areas is presented in figure 9.

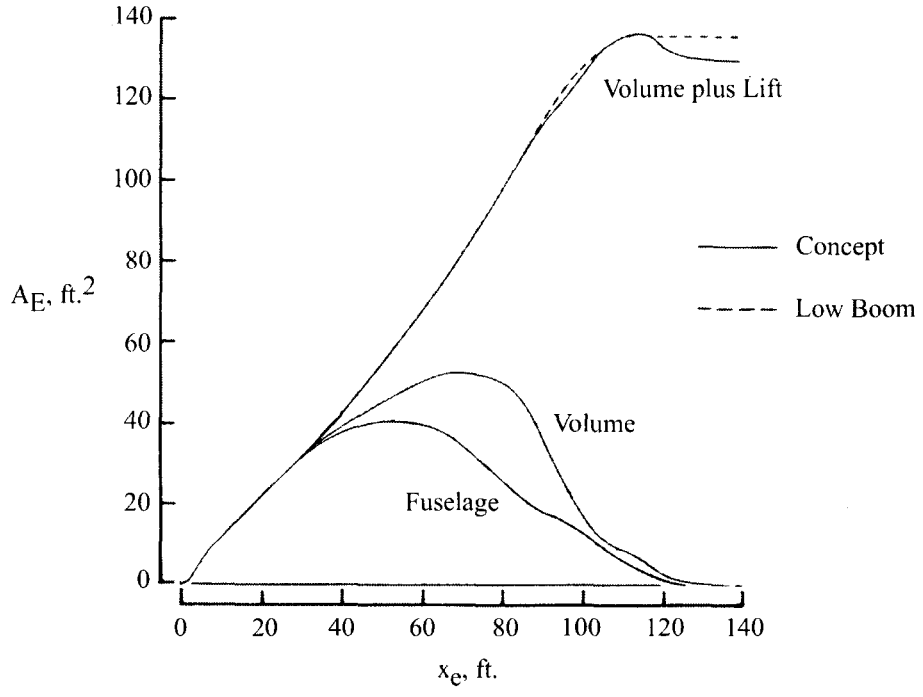


Figure 9. Summed equivalent areas, excluding nacelles, of the SBJ concept shown in figure 8. M = 2, W_c = 88,497 lb, and h = 53,000 ft.

The F-function calculated from the equivalent areas in figure 9 was then compared with a low-boom F-function that would lead to a nose-shock of 0.5 psf on the ground. APPENDIX F shows the shape of one ideal low-boom equivalent area curve, F-function, and their input parameters.

In figure 10, a comparison of the ideal and the calculated low-boom F-function of the wing, wing-lift, fuselage, canard, nacelle struts, and fin is shown.

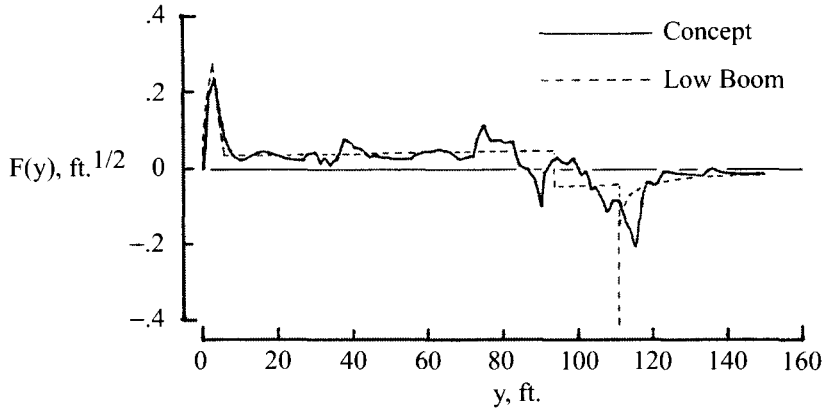


Figure 10. Comparison of ideal and calculated F-functions from the SBJ concept, without nacelles. M = 2, W_c = 88,497 lb, and h = 53,000 ft.

The agreement between the two F-functions is reasonably good along the nose section but there is poorer agreement once the wing volume and the lift equivalent areas start. These sections of poorer agreement show how sensitive the F-function can be to small differences between the desired areas, actual areas, and surface slopes when the fineness ratio of the fuselage is as low as it is on the SBJ concept. Increasing the number of input stations where areas are described on the fuselage, the wing volume, and the lift distributions might have reduced the "sawtooth" behavior in the positive section of the concept's total F-function.

Nacelle F-function

The nacelle F-function was calculated with the method of reference 15. With a finite inlet area and inlet lip angle, the nacelle F-function started with a singularity. As explained in reference 19, this singularity would not be properly treated by simply adding the nacelle and component equivalent areas. Figure 11 shows the F-function of the nacelle used on the concept.

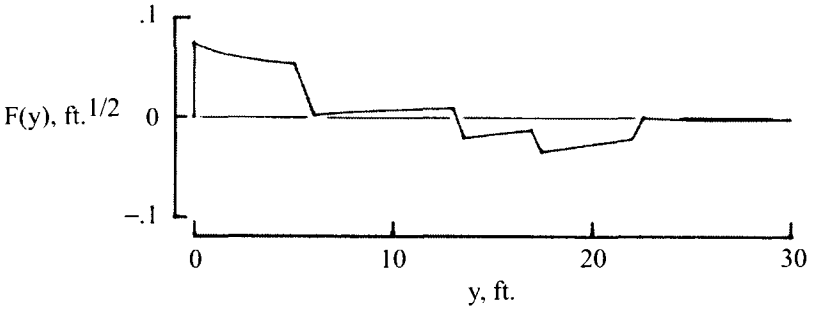


Figure 11. F-function of the nacelle for the concept's low-bypass-ratio engine.

Combined F-functions and Pressure Signatures

The complete aircraft Whitham F-function was obtained by adding two sets of F-functions. The first set was obtained from the summed smooth and continuous wing/wing lift/fuselage/canard/fin areas shown in figure 10. The second were the F-functions from each nacelle, figure 11. The beginning-cruise nacelle-on and nacelle-off F-functions are shown in figure 12.

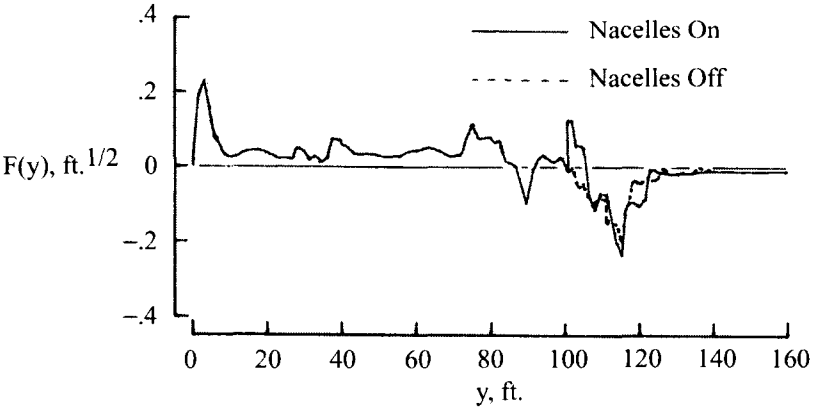


Figure 12. Nacelle-on and nacelle-off F-functions of the SBJ concept at beginning of cruise. M = 2, W_c = 88,497 lb, and h = 53,000 ft.

Ideally, the nacelle volume F-function would be added to the fuselage-wing-fin volume and wing-lift F-function at the longitudinal distance where the fuselage-wing F-function expansion began. However, the F-function in figure 12 shows the ideal was not completely achieved. Better agreement between the SBJ concept's wing/fuselage/fin/nacelle F-function and its theoretically ideal F-function might have been achieved by expending more effort in the fuselage tailoring, and/ or by using more stations in the volume and lift distribution. However, the relatively-low fineness ratio fuselage and locally strong lift gradients along the wing would still make it difficult to easily achieve all the potential low-boom characteristics.

Ground pressure signatures under the flight path at start of cruise were predicted from the summed, cruise-flight Whitham F-functions of the supersonic-cruise business jet concept shown in figure 12 using the prediction code from reference 12. A comparison of these pressure signatures with the ideal low-boom pressure signature is presented in figure 13.

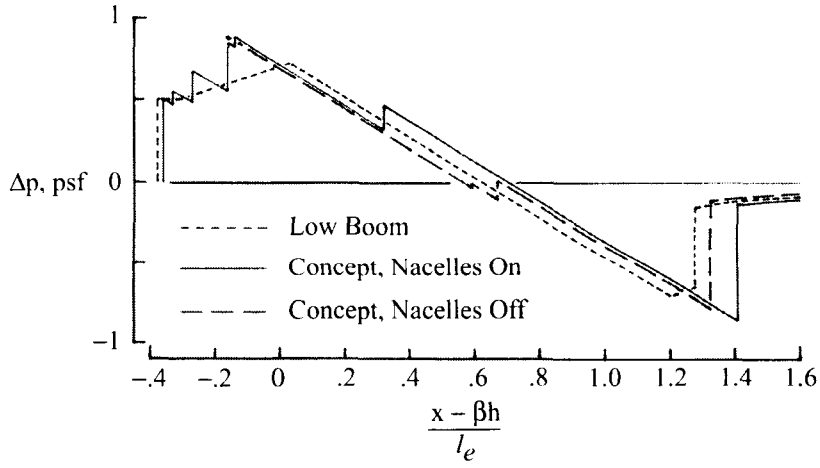


Figure 13. Predicted ground signatures from the SBJ concept with the canard at zero lift. M = 2, W_c = 88,497 lb, and h = 53,000 ft.

The differences between the ideal F-function, shown in figure 10, and the concept F-functions, shown in figures 10 and 12, lead to differences in the predicted ground pressure signatures shown in figure 13. These differences appeared as additional shocks, instead of a smooth, continuous, isentropic compression between the nose shock and the expansion to the tail shock. The engine nacelle F-function increments seen in figure 12 produced shocks in the expansion region of the predicted ground pressure signature shown in figure 13. These nacelle disturbances and their locations suggested that the nacelles were set close to, though not exactly at, the desired location for low boom characteristics. While the nacelles add a 0.15 psf increase in overpressure, the location of this pressure jump is too far aft for it to coalesce with the nose shock or with the in-between shocks during the pressure signature's propagation from cruise altitude to the ground. However, the overpressure slope on the ideal pressure signature as compared to the saw-tooth "ramp" overpressures on the calculated pressure signature should be a caution that the practical attainability of this ideal pressure signature must be checked by measurements in a wind-tunnel. Such tests would be needed to assure the pressure signature had a shape that "atmospheric freezing" would maintain as it propagated through a real atmosphere. When validated by experiment, further use of a "ramped" low-boom F-function could be trusted to design configuration components whose flow-field disturbances would survive from cruise altitude to the ground in a pressure signature shape that would produce a tolerable annoyance.

Check of Canard Takeoff Rotation Capabilities

The initial canard on the Langley low-boom SBJ was sized from canards found on previously designed SBJ concepts. Using the available estimates of weight, center of gravity, and takeoff velocities, this canard's area, shape, and location was used to obtain estimates of rotation capabilities. Results indicated the canard had inadequate capabilities; the concept could not takeoff at full thrust within 6000 feet. However, if the canard's area was increased as well as moved six feet further forward, an increased rotation rate and a shorter takeoff field length was obtained. A three-view sketch of the concept with this resized canard is presented in figure 14.

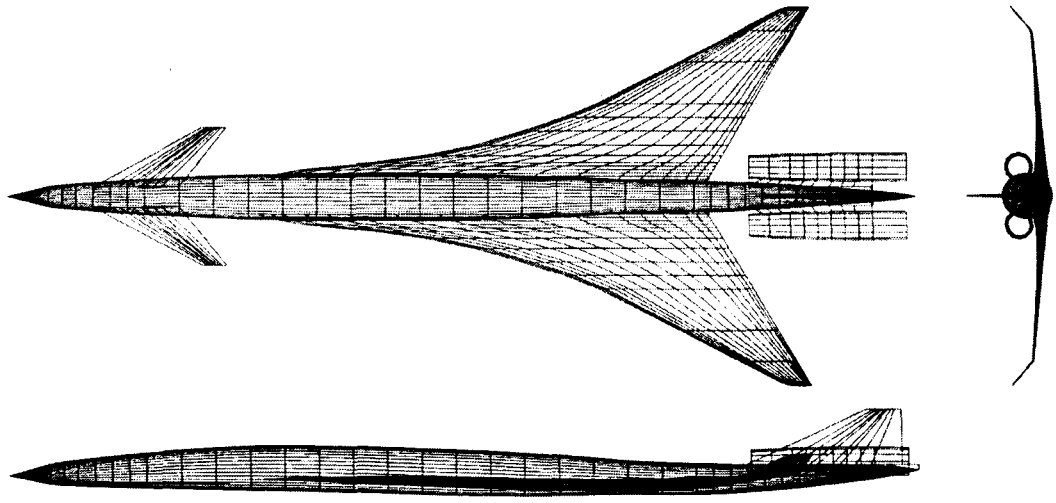


Figure 14. Three view of the Langley SBJ modified with a re-sized and re-located canard.

The new canard had a span of 20 ft, a projected area of 175 ft^2 (the initial canard had a span of 16 ft and a projected area of 123.2 ft^2), and a control surface area of about 111.5 ft^2. If trailing-edge flaps were also used, the 6000 foot takeoff specification could be met. The moment induced by the canard lift combined with the pitching moment due to the wing lift developed during rotation was sufficient to achieve the previously-calculated, full-thrust takeoff distance. However, canard deflections of about 30 degrees were required to initiate rotation, and this only after the main landing gear was moved forward by a foot.

Another promising design approach briefly studied was a straight, tapered canard. Its span was kept the same as the previous canard at 20 ft, its projected area was 150 ft^2, its control surface area was 112.0 ft^2, and its aspect ratio was 2.67. This canard's position was lowered in an attempt to maintain the limited visibility available to the pilot and co-pilot, and it was moved forward similar to the resized and relocated canard previously described. There would be a wave drag penalty associated with this new canard, and the forebody would have its area-ruled volume reshaped, but this would also have to be done with the previous resized and relocated canard.

This straight tapered canard shape had the advantage of improved low-speed aerodynamic efficiency. Much less canard deflection was required to obtain the required rotational authority, and if the flap-assisted wing was to aid in generating pitch-up moments, the canard's deflection would be about 20 degrees instead of approximately 30 degrees required with the previous resized canard. However, the canard's supersonic leading edge at cruise Mach number would require special attention during the area-rule tailoring of the nose and the sonic boom analysis of the concept.

A three-view sketch of the concept with the straight, tapered-planform canard is presented in figure 15.

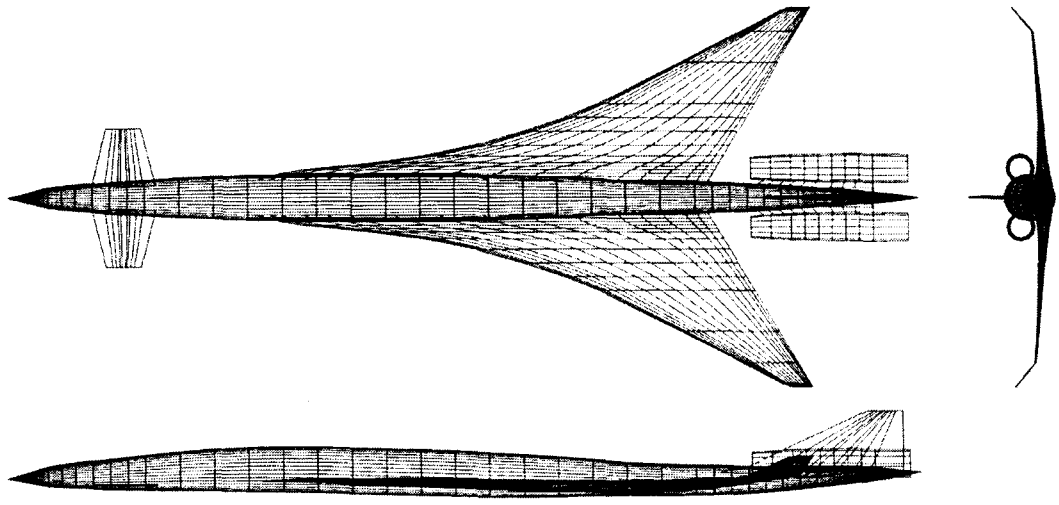


Figure 15. Three view of the Langley SBJ modified with a straight, tapered canard.

Areas and aspect ratios of the new canards were larger than the original, so their equivalent area distributions extended over different effective lengths. The effective length of the swept-leading-edge canard would obviously be longer than that of the straight, tapered canard, so bit more area-ruling would be needed along the nose and forebody. However, neither the usable volume nor the concept's sonic-boom, nose-shock characteristics would be greatly changed if the nose tailoring were done carefully, especially the nose tailoring due to the presence of the tapered canard. Thus, the three-view sketches in figures 14 and 15 illustrate two possible solutions to a takeoff field length problem encountered in the design of a SBJ, especially one with aft-fuselage mounted engines, a low-speed-control canard, and low-boom requirements.

Check of Fin Effectiveness Under Engine-Out Conditions

As was previously mentioned in the section on fin design, the fin area on the Langley SBJ concept was sized by proportioning the areas of fins found on HSCT and previously-designed SBJ concepts. Once the engine size had been determined, takeoff control effectiveness of this fin/rudder could be calculated, using the first-order method described in reference 26. Calculations performed with this method indicated that with a (rudder area)/(fin area) ratio of 0.35, a maximum rudder deflection of 30 degrees would neutralize the one-engine-out thrust moment during takeoff at a critical velocity of about 192 ft/sec. Rudder power was improved by increasing the fin area from 109 ft^2 to 130 ft^2, with the (rudder area)/(fin area) ratio kept constant. The Langley low-boom SBJ with the new fin-rudder is shown in figure 16.

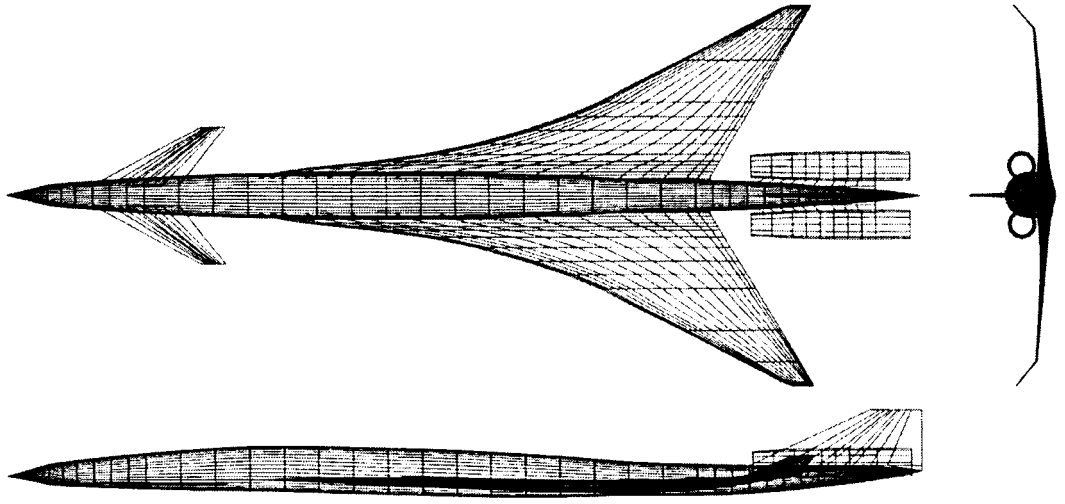


Figure 16. Three view of the Langley SBJ modified with a re-sized, re-located canard, and a re-sized fin/rudder.

This increase in fin area reduced the critical velocity from 192 ft/sec to about 167 ft/sec. Since the velocity at the moment of takeoff rotation was about 276 ft/sec, it was assumed that either rudder should be sufficient for engine-out control.

Results

This design study demonstrated that the design of a long-range low-boom SBJ could be just as technically difficult and demanding as the design of a 300-passenger low-boom HSCT. The sources of these difficulties were: (1) a ground overpressure reduced from 1.0 psf to 0.5 psf; (2) a low-boom tailored wing with a maximum area loading of from 55 to 65 psf, and an aspect ratio of about 2.0; (3) a fuselage fineness ratio that was significantly smaller than on a 300-passenger HSCT; (4) a wing volume sufficient to hold part of the required mission fuel and the landing gear struts; (5) a fuselage volume sufficient for the crew's cabin, the passenger compartment, most of the fuel volume, wheel stowage, and engine-support structure; (6) an engine nacelle location on the aft fuselage; (7) a canard sized and located for both low-boom characteristics and sufficient takeoff rotation capabilities; and (8) a beginning-cruise weight to beginning-cruise altitude match which satisfied sonic-boom constraints of a specified ground overpressure, and mission constraints of a L/D ratio high enough to make the specified range.

The reduced overpressure level, difficulty (1), seemed possible to achieve because of the large reduction in beginning-cruise weight. However, this weight reduction was accompanied by a corresponding reduction in effective length. This effective length reduction offset, to a large extent, the effects of the weight reduction in obtaining a lower ground overpressure.

The low-boom wing planform constraint, difficulty (2), was an expected source of aspect ratio/area problems. The compromises made on the Langley SBJ provided a reference area of about 1650 square feet, a lifting length of about 84 feet, and an aspect ratio of about 1.94 . These compromises made in the design of the 10-passenger SBJ were very similar to those made in the design of 300 passenger long-range supersonic-cruise vehicles.

Fuselage volume constraints, difficulty (3), created both aerodynamic penalties through increased wave drag, and low-sonic-boom penalties through increased equivalent area. This effect was countered with an increased length even though it meant an incremental increase in the empty weight. If the ground

overpressure had a specified range rather than a single value, and there were drag increments available for trades, the cabin volume could be increased to improve passenger comfort at the expense of range reduction, and a somewhat higher sonic-boom overpressure.

Difficulty (4) was met with increased airfoil thickness and by varying the maximum thickness location along the semispan. The result was an incremental increase in the concept's wave drag.

Difficulty (5) was overcome with a longer fuselage length. Although the extra length increased the empty weight, it enhanced the possibilities for low sonic boom.

Difficulty (6) arose from moving the engine nacelles from the conventional location under the wing. Other possible engine nacelle locations, rather than on the aft fuselage, exist, but there was no time to fully explore their effects on mission performance and sonic boom.

Canard size and location, difficulty (7), resulted from the selection of a canard, rather than a horizontal tail or a combination of the two, as a means for low-speed control and maneuverability. As with engine nacelle location, there was insufficient time to fully explore the use of more than two other auxiliary surfaces to control the vehicle at low speeds.

As with difficulty (2), difficulty (8) would be present in the design of all low-boom supersonic-cruise concepts. It would be met by modifying low-boom features and compromising mission range performance while still meeting both requirements. This type of cross-purpose design adjustment can often be achieved by starting with a slightly lower overpressure design limit and a slightly longer mission range.

Two off-the-shelf engines with adequate thrust and performance for the needs of the low-boom SBJ were not found. So, hypothetical engines with thrust and performance characteristics dictated by takeoff and cruise requirements were used. As with other concepts that eventually were successful, there was the expectation that an appropriate engine would be developed if political, mission, market, environmental, and safety constraints were fully met.

Concluding Remarks

Low/reduced-sonic-boom methodology and high aerodynamic efficiency methods developed during the past thirty-five years were found to be useful and applicable in the design of a low-boom SBJ concept capable of generating a ground overpressure of about 0.5 psf under the flight path at start of cruise. Design and analysis procedures applied during the SBJ concept design encountered similar areas of technical difficulty that were found during the preliminary design of a low-boom HSCT. The following difficulties encountered in the design of the SBJ which would achieve the desired ground overpressures were especially difficult to overcome: (1) a length less than 140 feet; (2) a beginning-cruise weight that had to be less then 85,000 to 90,000 pounds; and (3) a gross takeoff weight of 100,000 pounds or less. There were also the usual problems of matching the concept's equivalent areas to an ideal low-boom equivalent area while maintaining a reasonably low wave drag with a fuselage fineness ratio of about one-half to one-third that of a fuselage on a HSCT concept.

Locating the engine nacelles so their disturbances were reduced by the low pressures in the concept's expansion region severely limited the engine-mounting choices. The drop in local expansion pressures was only about a third of that found on a HSCT concept, but the nacelle inlet disturbances had about the same shock strengths. Location of the nacelles on the Langley SBJ concept depended on these factors,

and on the premise that there was sufficient structural strength to support two engines, nacelles, struts, and auxiliary equipment at the selected aft-fuselage location.

Some re-sizing of the canard and the fin was found to be necessary. However, the re-tailoring of the fuselage for low-boom characteristics was anticipated to be small relative to the changes made to the canard for improved takeoff rotation capabilities, and to the fin, for better engine-out-on-takeoff performance. It was recognized that there would be weight penalties associated with these component re-sizings. These penalties were assumed to be negligible and well within the range of weight adjustments capable of being absorbed by the empty weight once a better idea of the true fuel consumption and concept weight was obtained by a more extensive performance analysis.

Although the Langley SBJ concept achieved some measure of success as a demonstration of the applicability of both high aerodynamic efficiency and low/reduced sonic-boom methodology, this success was obtained by advocating advanced materials and advanced propulsion technology. "Synthetic" external vision would also be needed to preserve the low-boom nose shape. Even with these advanced technologies, a considerable amount of optimistic signature shaping was required so that the sonic boom overpressures at start of cruise, at ground level, and under the flight path were equal or less than the 0.50 psf specified. In view of these results, it seems logical to believe that high-technology composite materials, and the development of new engines capable of the required fuel performance, noise suppression, and emission suppression characteristics would be necessary to achieve a technically, economically, and environmentally viable low-boom SBJ.

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Appendix A

Characteristics of the Low-Boom Business Jet Concept

Span, ft	55.0
Overall Length, ft	132.5
Wing Area (reference), $ft.^2$	1,560.25
Wing Mean Aerodynamic Chord, ft	42.02
Wing Aspect Ratio (projected area)	1.93
Fin Area (initial), $ft.^2$	108.6
Canard Area (initial, projected), $ft.^2$	123.2
Number of Passengers	10
Range, nmi.	4,000.0
Cruise Mach Number	2.0
Gross Takeoff Weight, lb	99,435.0
Beginning Cruise Weight, lb	88,497.0
Beginning Cruise Altitude, ft	53,000.0
End Of Cruise Weight, lb	51,100.0
End Of Cruise Altitude, ft	64,490.0
Zero-Fuel Weight, lb	44,134.0
Empty Weight, lb	41,434.0
Number of Engines	2
Thrust/Engine, lb	20,300
Mission Fuel Weight, lb	49,336.0
Reserve Fuel Weight, lb	5,966.0

Appendix B

Estimate of the Empty-Weight and Zero-fuel Weight Center of Mass of the Low-Sonic-Boom Business Jet Concept

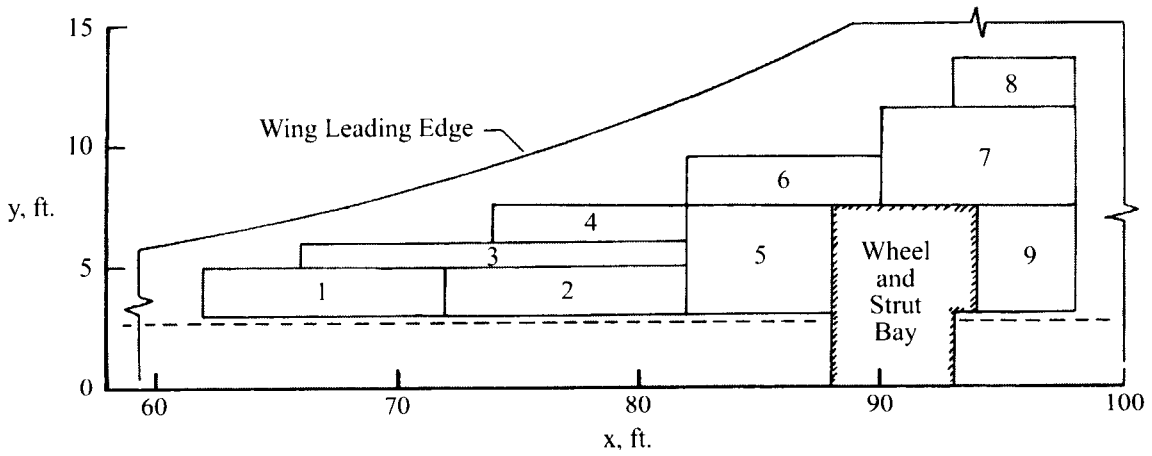
Component	Weight, lb	Center of Mass, ft
Wing and Fuel Tanks	11,750.0	91.0
Fuselage and Fuel Tanks	9,835.0	71.0
Canard	450.0	33.0
Fin(s)	600.0	123.0
Engine(s)	8,500.0	124.0
Nacelle(s)	1,000.0	122.0
Nacelle Strut(s)	800.0	119.0
Front Landing Gear	500.0	25.0
Main Landing Gear	3,800.0	91.0
Misc. (Instruments, furnishings, etc.)	4,200.0	65.0
Empty Configuration Weight	**41,435.0**	**90.7**
Crew and Payload		
Crew	450.0	26.0
Passengers and Baggage	2,250.0	45.0
Sub-Total	**2,700.0**	**41.8**
Zero-Fuel configuration Weight	**44,135.0**	**87.7**

Appendix C

Estimate of the Center of Mass of the Fuel in the Low-Sonic-Boom Business Jet Concept

Wing Tanks

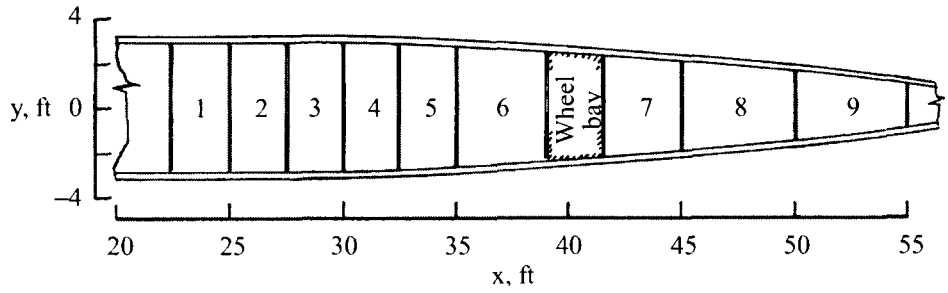
The wing fuel tanks were drawn as blocks for ease in calculating volume and center of gravity. Their walls are along airfoil chord lines, but not along constant-percent chord lines.



Wing Fuel, Tank No.	Weight, lb	Center of Mass, ft
1.	1,650.0	68.46
2.	2,090.0	77.26
3.	1,080.0	75.75
4.	700.0	79.41
5.	2,500.0	84.95
6.	890.0	86.77
7.	1,430.0	94.50
8.	280.0	95.63
9.	920.0	95.80
Total Wing Fuel Weight	**11,540.0**	**82.45**

Fuselage Tanks

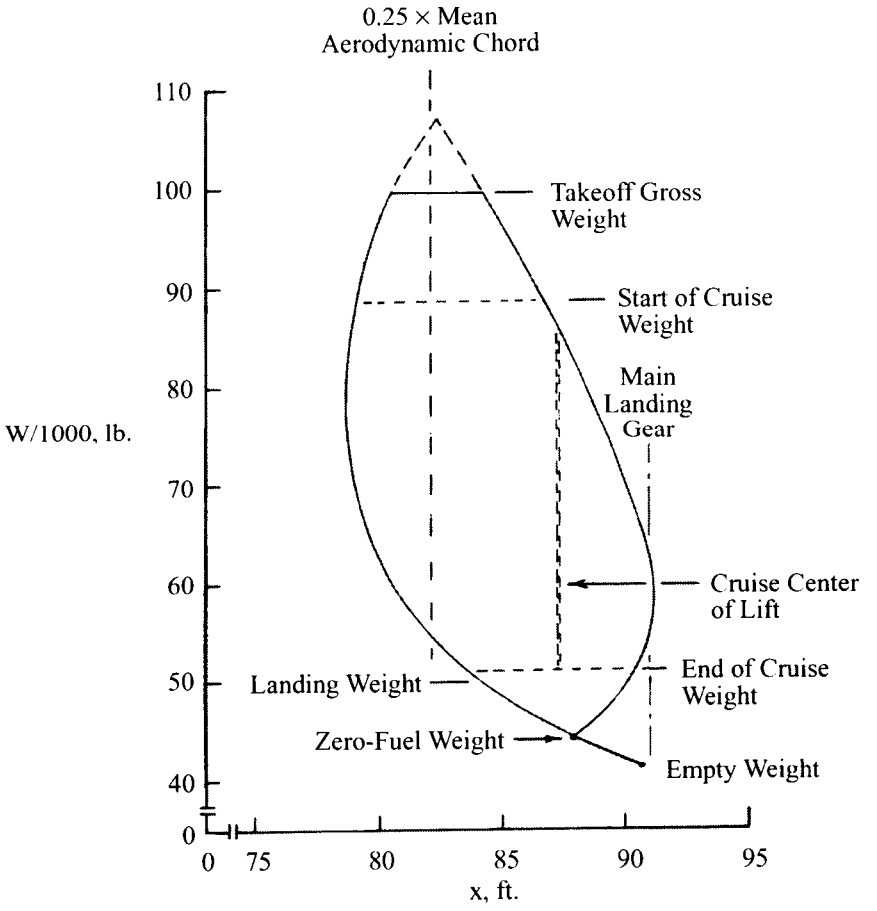
The fuselage fuel tanks were sized for ease in calculating volume and center of gravity.



Fuselage Fuel, Tank No.	Weight, lb	Center of Mass, ft
1.	6,830.0	57.50
2.	6,760.0	62.49
3.	6,535.0	67.48
4.	6,095.0	72.46
5.	5,530.0	77.45
6.	7,650.0	83.87
7.	4,670.0	96.36
8.	4,765.0	104.61
9.	2,365.0	114.15
Total Fuselage Fuel Weight	**51,200.0**	**77.85**
Net Fuel Weight	**62,740.0**	**78.70**

Appendix D

Estimated Center of Mass Boundaries of the Low-Boom Business Jet Concept



Appendix E

Estimated Centers of Mass of the Low-Boom Business Jet Concept at Key Mission Points

Gross Takeoff

Component	Weight, lb	Center of Mass, ft
Configuration, Empty	**41,435.0**	90.7
Crew and Payload	**2,700.0**	41.8
Configuration, Zero-Fuel	**44,135.0**	**87.7**
Total Wing Fuel	**11,540.0**	**82.5**
Total Fuselage Fuel	**43,760.0**[1]	**81.2**
Net Fuel Weight	**55,300.0**	**81.5**
Gross Takeoff Weight	**99,435.0**	**84.3**

Start of Cruise at M = 2.0

Component	Weight, lb	Center of Mass, ft
Configuration, Empty	**41,435.0**	90.7
Crew and Payload	**2,700.0**	41.8
Configuration, Zero-Fuel	**44,135.0**	**87.7**
Total Wing Fuel	**11,540.0**	**82.5**
Total Fuselage Fuel	**32,825.0**	**86.8**
Net Fuel Weight	**44,365.0**	**85.6**
Start of Cruise Weight	**88,500.0**	**86.7**

[1]Fuel was moved aft to decrease distance between c.g. and main wheels. The same mass of fuel could be moved forward to have the c.g.and the 0.25*m.a.c. coincident. Obviously, the canard deflection for rotation at the more forward c.g.location would be greater.

Estimated Center of Mass of the Low-Boom Business Jet Concept

End of Cruise at M = 2.0

Component	Weight, lb	Center of Mass, ft
Configuration, Empty	**41,435.0**	90.7
Crew and Payload	**2,700.0**	41.8
Configuration, Zero-Fuel	**44,135.0**	**87.7**
Total Wing Fuel	**0.0**	----
Total Fuselage Fuel	**6,965.0**	**84.6**
Net Fuel Weight	**6,965.0**	**84.6**
End-of-Cruise Weight	**51,100.0**	**87.3**

Start of Subsonic Descent**

Component	Weight, lb	Center of Mass, ft
Configuration, Empty	**41,435.0**	90.7
Crew and Payload	**2,700.0**	41.8
Configuration, Zero-Fuel	**44,135.0**	**87.7**
Total Wing Fuel	**0.0**	----
Total Fuselage Fuel	**6,965.0**	**57.8**
Net Fuel Weight	**6,965.0**	**57.8**
Start of Subsonic Descent Weight	**51,100.0**	**83.6**

**Rapid deceleration and transfer of fuel is assumed

Landing

Component	Weight, lb	Center of Mass, ft
Configuration, Empty	**41,435.0**	90.7
Crew and Payload	**2,700.0**	41.8
Configuration, Zero-Fuel	**44,135.0**	**87.7**
Total Wing Fuel	**0.0**	----
Total Fuselage Fuel	**5,965.0**	**57.5**
Net Fuel Weight	**5,965.0**	**57.5**
Landing Weight	**50,100.0**	**84.1**

Appendix F

Parameters Used To Calculate the SBJ Equivalent-Area Distribution and an F-function Mach Number, M = 2.0

Beginning-Cruise Altitude, h = 53,000 ft
"Nose-Bluntness" Length, y_f = 6.0 ft
"Flat-Top" Section of F-Function, $\xi - y_f$ = 10.0 ft
Beginning-Cruise Weight, W_c = 88,457.0 lb
"Low-Boom, Equivalent-Area" Cruise Weight, W_{eff} = 92,809.4 lb
Effective Length, $l_c = l_{cp}$ = 111.0
Ground Overpressure, Δp = 0.5 psf
η = 0.35 (η = 0.0 is a flattop signature)
Ground Reflection Factor = 1.9
Maximum value of A_E (at $y = l_c$) = 136 ft^2

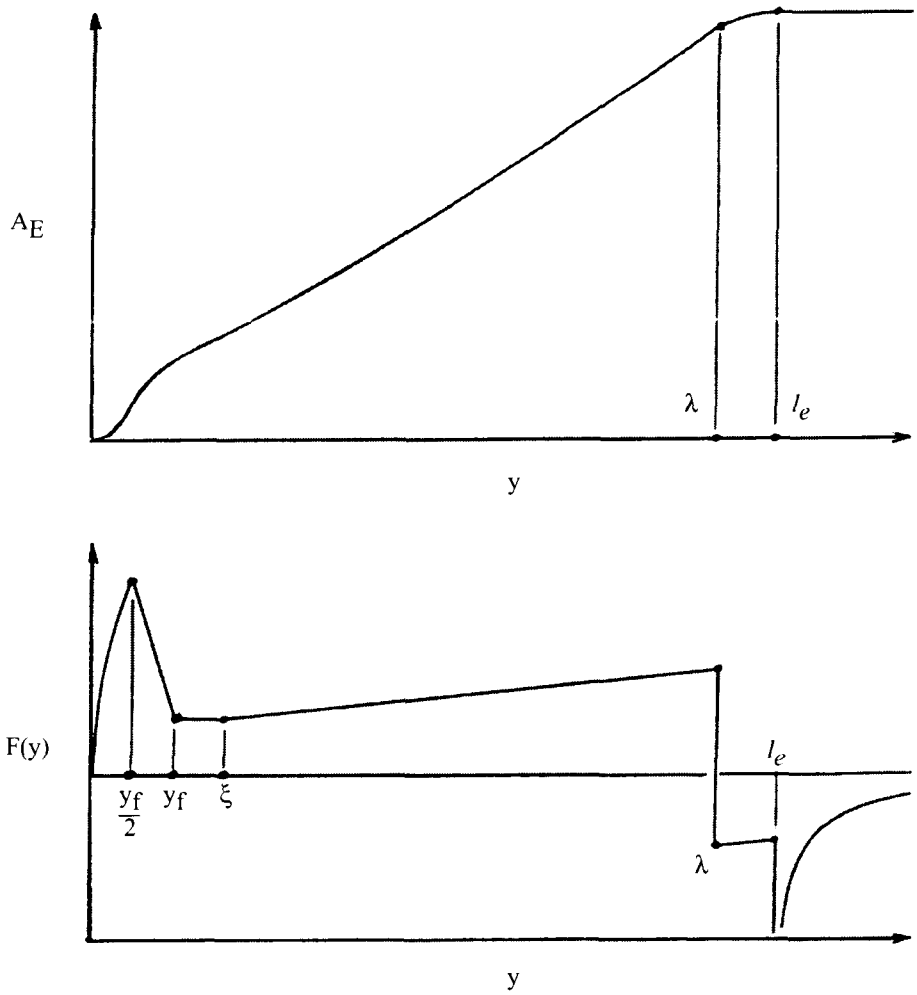


Figure F1. Theoretical low-boom equivalent area and F-function for SBJ concept. There are no scales so subtle features can be exaggerated for clarity.

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14. ABSTRACT

Ongoing human-response studies of sonic-boom noise indicated that a previous level of 1.0 psf might still be too annoying. This led to studies of a Supersonic Business Jet (SBJ), which might generate lower, more acceptable ground overpressures. To determine whether methods for designing a High Speed Civil Transport (HSCT) could be successfully applied, a SBJ concept was designed at the langley Research Center. It would cruise at Mach 2, carry 10 passengers for 4000 nautical miles, and generate a 0.50 psf or less on the ground under the flight path at start of cruise. Results indicated that a 10-passenger, low-boom SBJ design was just as technically demanding as a 300-passenger, low-boom HSCT design. In this report, the sources of these technical problems are identified, and ideas for addressing them are discussed.

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Sonic boom; Whitham theory; Modified Seebass and George minimization; Low-boom business jet design

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